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Metatarsal Boot Safety When Ascending Stairs

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Abstract

Appropriate footwear is an important component to preventing slips, trips, and falls. The mining industry has been using safety-toe work boots for many years and the industry commonly accepts them as a safe choice of footwear given the workplace hazards and terrain. Recently, metatarsal boots are becoming more commonplace. A key feature of the metatarsal boot is the extension of the foot protection beyond the toe area to an area that covers the 1st through 5th metatarsal bones. This added protection raises concerns with range of motion, proprioception, and overall flexibility of the foot. The National Institute for Occupational Safety and Health conducted research to determine the effects of this added metatarsal protection on toe-clearance when ascending stairs. Participants wore hiker-style work boots of similar design and construction, one with steel-toe protection and the other with steel-toe and metatarsal protection. While wearing these boots, participants ascended stairs and the motion of their boots was tracked using a motion capture system. The distance from the toe of the boot to the edge of the middle step was determined. Results of the study are presented and implications of the research are discussed.

Keywords
Metatarsal boots, stair ascent, toe clearance, fall, trip

1. Introduction
In the U.S. mining industry, slips and falls are the second largest contributor to non-fatal injuries. Slips, trips, and falls (STFs) may be caused by a variety of factors, including workplace design, the presence of environmental contaminants, and inappropriate footwear. Footwear is an important component to preventing STFs because it is the primary interface between the mine worker and the physical work environment. Protective, safety-toe footwear has been used in the mining industry for many years, and it is commonly accepted as a safe choice of footwear given the workplace hazards and terrain of the mining environment.

Recently, mining companies have started to require the use of metatarsal work boots instead of the traditional safety-toe footwear. A key feature of the metatarsal boot is the added protection over the 1st through 5th metatarsal bones. This protection is in addition to the safety-toe feature of the traditional work boot that protects the phalanges. While metatarsal protection may be effective at protecting a greater portion of the foot from injuries, a common belief is that metatarsal boots may increase the risk for a slip, trip, or fall compared to the traditional safety-toe boot. The design of the metatarsal boots with a larger, rigid portion over the forefoot could restrict motion of the metatarsals, potentially affecting the flexibility and proprioception of the foot and ankle. Reduced awareness of foot position may contribute to falls by attenuating the plantar tactile sense and reducing stability [1]. Reduced ankle range of motion may not present a significant issue during level walking, but there is an increased need for this flexibility when traversing stairs [2]. Reduced metatarsal motion has also been shown to decrease ankle joint movement in the sagittal plane [3]. As such, metatarsal flexibility is important to ensure safety during stair ascent.

Stair-related STF risks have been examined in limited populations, including persons with neurological impairments, elderly individuals, and firefighters [4-6]. The general view is that a person is at more risk for a fall during stair descent, as compared to stair ascent. However, when ascending stairs, the need for foot flexibility is greater. During stair ascent, the forefoot is the primary location of contact between the foot and the stair [7]. When attempting to place the forefoot on the stair tread, the implications of any reduction in metatarsal or ankle flexibility will affect toe clearance. Decreased toe clearance increases the risk for a trip over the stair edge which may lead to a fall [6].

The use of metatarsal boots in mining is increasing, and the effect of the added metatarsal protection on STF risks remains unknown. Any reduction in foot flexibility while wearing metatarsal boots may affect toe clearance when ascending stairs, leading to increased risk for a STF. No research was found that examined the impact of metatarsal boots versus steel-toe boots on fall risks during stair ascent. Mining companies should be informed of the implications of metatarsal boots to determine if the risk of a slip, trip, or fall due to wearing metatarsal boots (versus safety-toe boots) outweighs the benefits of the added foot protection. The goal of the research discussed in this paper was to determine if wearing a metatarsal boot compared to a steel-toe only boot while ascending stairs increases the risk for a fall by decreasing toe clearance.

2. Methods

2.1 Overview

The five participants for this study were recruited from the employee population at the National Institute for Occupational Safety and Health who were involved in a larger study examining heel clearance, toe clearance, and foot placement when ascending and descending stairs. A subset of these participants were used for the purpose of this analysis because they all wore the same-sized shoe and therefore wore the exact same boot. This allowed for a more accurate comparison of toe clearance as the location of the markers on the boots remained unchanged. The demographics of the five participants included in this analysis are shown in Table 1. After reading and signing an informed consent document approved by the National Institute for Occupational Safety and Health Institutional Review Board, participants were given an overview of the research process.

Two types of boots were used for this study—steel-toe only and steel-toe with metatarsal protection. For standardization, all participants wore the same two pairs of boots. Many manufacturers have significant differences in the overall boot design and tread features between steel-toe and metatarsal boots. However, one manufacturer was identified as having near exact models of boots—one model with steel-toe only and the other with steel-toe plus metatarsal options; these are the two boot models selected for use in this study. The boots are men's U.S. size 10 Dr. Marten's Ironbridge Steel Toe Model DMR12721001 weighing 1.03 kg and Dr. Marten's Ironbridge Steel Toe Met Guard Heritage Model DMR14403001 weighing 1.16 kg (see Figure 1). The order of testing was randomized, and participants were given a pair of boots and instructed to walk around the test area to get acclimated to wearing the boots. Once the participants said they were comfortable in the boots, the study began. Participants were instructed to walk at a self-selected pace up the stairway without grasping the handrails and to stop when they reached the top (see Figure 2). They were then allowed to walk back down. Participants walked up the stairs five times (only the 5^{th} trial was analyzed) before switching to the next boot.

Table 1: Demographics of participants

Participant ID	Age (years)	Height (cm)	Weight (kg)
1	22	183	68
2	33	178	95
3	24	175	82
4	34	175	93
5	27	173	73
Average ± St dev	**28 ± 5.3**	**177 ± 4**	**82 ± 12**

2.2 Instrumentation

A motion capture system (Eagle Motion Tracking System, Motion Analysis Corporation, Santa Rosa, CA, USA) was used to track the motion of the foot when ascending the stairs. All boots were instrumented with reflective motion capture markers at locations on the toe, heel, and sides of the boots (see Figure 1). The toe marker was placed such that it was located on the top of the boot, 3.8 cm posterior of the center edge of the toe region. The vertical distance from the base of the marker to the base of the boot outsole was also measured and recorded. For the metatarsal and steel-toe boots, the base of the toe marker was 6.25 cm and 5.74 cm above the middle of the bottom sole, respectively. The toe area of the metatarsal boot was 0.51 cm taller than the steel-toe boot. The stairway was also instrumented with reflective markers on the outermost edges of the third step.

Figure 1: Steel-toe (left) and metatarsal (right) boots used in the study with the toe markers attached.

Figure 2: Laboratory setup showing a participant ascending the stairs.

2.3 Data Analysis

Motion capture data was imported into Matlab (The MathWorks Inc., Natick, MA, USA) for subsequent analysis. For this analysis, toe clearance was defined as the distance from the toe marker to the marker on the third step edge at the last data sample where the toe marker was beneath the third (middle) stair edge before landing on the stair. Since all participants wore the exact same shoes, it was not necessary to transpose the location of the marker to any other landmark. Moreover, it has been shown that during stair ascent, marker locations within the toe region can be used to accurately determine minimum foot clearance [8]. The X (anterior/posterior), Z (superior/inferior), and resultant toe clearances were calculated.

2.4 Statistical Analysis

Paired samples T-Tests were conducted to determine if there were statistically significant changes in toe clearances when wearing the metatarsal boots as compared to the steel-toe only boots. An alpha level of 0.05 was used for these analyses.

3. Results

All participants transitioned from the second to the third stair with the right foot first. As such, all reported values are for the right foot. Paired samples T-Tests revealed no statistically significant differences in toe clearances between the metatarsal and steel-toe boots for the X clearance (t(4)= -1.844, *p*= 0.139), Z clearance (t(4)= -.137, *p*= 0.897), or resultant clearance (t(4)= -1.747, *p*= 0.156). Resulting toe clearances including overall means and standard deviations are provided in Table 2.

Table 2: Toe clearances for all participants, by boot type

PARTICIPANT ID	BOOT TYPE	TOE CLEARANCE (CM)		
		X	Z	RESULTANT
1	Metatarsal	1.72	-0.72	1.86
	Steel-toe	1.28	-0.52	1.38
2	Metatarsal	23.45	-0.19	23.45
	Steel-toe	24.86	-7.2	24.87
3	Metatarsal	8.0	-0.83	1.15
	Steel-toe	3.43	-0.36	3.44
4	Metatarsal	4.09	-1.19	4.26
	Steel-toe	3.98	-0.65	4.03
5	Metatarsal	18.39	-0.25	18.40
	Steel-toe	20.44	-0.76	20.46
AVERAGE ± ST DEV	Metatarsal	9.69 ± 10.48	-0.64 ± 0.42	9.83 ± 10.35
	Steel-toe	10.80 ± 10.98	-0.6 ± 0.16	10.84 ±10.95

4. Discussion

Steel-toe work boots are commonly worn by mine workers to protect their feet from the potentially hazardous environment. Recently, more mining companies are starting to require that their mine workers wear metatarsal work boots. However, the added weight and restrictive structure on the forefoot has the potential to restrict movement. This study aimed to determine the effect of metatarsal protection on toe clearance when ascending stairs. The added metatarsal protection was not shown to affect toe clearance for the boots tested.

There was considerable variability in the toe clearances exhibited by the participants in this study. However, the within-subject differences between the boot types was minimal. It is unclear what would have caused such a large difference among participants. This could have been caused by the normal difference in typical walking styles or changes in walking styles associated with wearing work boots. A comparison to “normal” would need to be made to determine if some, or all, participants modified their normal walking patterns due to wearing the work boots provided. The shaft height, weight, or sole flexibility of the work boots has been previously shown to affect gait and may have caused modifications in walking style as compared to the participants’ normal walking shoes [3, 9].

Boot weight has been shown to affect trailing toe clearance when crossing obstacles, with heavier boots showing reduced toe clearances [9]. The boots in this study were of similar weight with the metatarsal boots only weighing 0.13 kg more than the steel-toe boots. It is possible that the boots were not different enough to result in any measurable changes in toe clearance. In that respect, the added metatarsal protection is a useful feature to improve mine worker safety while minimizing any harmful effects. Future research will be necessary to determine if the added weight of the metatarsal work boot increases the risk of muscle fatigue. Heavier boots have been shown to decrease toe clearance when crossing obstacles due to decreased stability and control [6]. The effect of the increased boot weight on toe clearance could not have been determined from this study because the participants were not fatigued and had not worn the boots or walked for any prolonged period prior to participation in this study.

5.1 Limitations

This paper presents results from a small sample size and does not allow for making general conclusions about toe clearances. All participants wore new boots that they do not normally wear. The participants may not have been truly comfortable in either pairs of boots, resulting in higher toe clearances than what may have been found when wearing their own boots. Moreover, the results from testing these specific boots may not be generalizable to all metatarsal and steel-toe boots as there is a potential for larger differences in weight, sole stiffness, and shaft height. A larger, more diverse participant and boot pool will be necessary to determine if metatarsal protection affects gait, fatigue, or flexibility, which could increase the risk for a slip, trip, or fall at work.

6. Conclusion

This study examined the impact of added metatarsal protection on toe clearance when ascending stairs. Results showed no significant differences in toe clearances between the metatarsal and steel-toe boots tested. It is unlikely that the metatarsal boot studied would increase the risk of a fall due to tripping when ascending stairs. Future research is needed to assess a larger, more diverse sample of participants and work boots. Stair climbing is only one activity for which foot flexibility is important. Descending stairs, ascending and descending vertical ladders, and ascending and descending inclined walkways are also common tasks that require more ankle flexibility than level walking. These activities should also be examined to determine if metatarsal boots adversely affect a mine worker's risk for a slip, trip, or fall.

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Disclaimer

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